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# MEASUREMENT OF TOTAL SEDIMENT BEDLOAD TRANSPORT IN EPHEMERAL MOUNTAIN STREAMS

by

Paul F. Ruff

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ROCKY MOUNTAIN STATIC

Arizona State University
Civil Engineering
February 1979

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ACKNOWLEDGEMENT

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## ABSTRACT

The management of the mountainous forested watersheds of the Southwest may be evaluated by determining the correlation between land use practices and the resulting changes of sediment concentrations in the ephemeral streams of the watershed. Hydraulic laboratory studies were conducted to determine the suitability of the slot trap and the vortex tube ejector to accurately measure the quantity of large-sized sediments transported in water channels. Stream velocities of approximately 5 ft. per second and Froude numbers greater than 1.0 were required to produce incipient sediment motion. The slot trap design almost immediately filled with sediment after initiating the water and sediment study conditions. The vortex tube ejector was determined to be a suitable device for measuring the total bedload carried by high velocity water flows.

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# INTRODUCTION

An important aspect of the evaluation of resource management alternatives for watersheds in the Southwest is the determination of the relationship of erosion, with the resulting sedimentation, and management practices on forested areas. One of the most difficult and crucial aspects of the problem is the determination of the size gradation and quantity of sediment material carried as bedload in the watershed streams. Theoretical equations have been developed for quantitatively predicting bedload transport rates. However, the basic assumptions upon which these theoretical equations have been derived are not applicable to mountain streams because of their steep slopes and large variation of sediment sizes, that range from fine sand to boulders.

The ephemeral nature of mountain streams limits the type of physical facilities that can be used to measure the bedload transport. The flows that occur in Southwest mountain streams are the result of snowmelt and summer thunderstorms. Time and location of occurrence of summer storms are difficult and usually impossible to predict. During winter the access roads to sediment measuring sites are generally impassable. Sediment measuring apparatus design must, therfore, permit the apparatus to be in place before any flow in the streams exists, be operable with no supervision, and retain all of the intercepted sediment during the period of streamflow.

No investigations have been performed in which the total

bedload of ephemeral mountain streams has been successfully measured. Apparatus has been used for the measurement of coarse bedload material, but only for sizes generally not exceeding an equivalent particle diameter of 70mm. These facilities are of large cost and require constant supervision and maintenance. The Helley-Smith bedload sediment trap has been redesigned to increase the four-inch square opening to a six-inch square opening, but this change yields only limited additional information pertaining to the total bedload movement of mountain streams.

Trenches, or slot traps, excavated perpendicular to the stream channel have been used to catch the sediment as it moves along the stream bed. The quantity of sediment intercepted by the trenches is measured volumertically or pumped into a weighting tank. This facility require supervision or must be made large enough to accumulate the entire stream bedload transport during any period of flow. Investigators have determined that the results obtained from the slot trap method are most accurate for small streams with uniform flow conditions. These requirements make slot traps not practical for use in the watersheds of the Southwest.

The vortex tube ejector consists of slot-opening in the crown of a tube. The device is buried to a depth of the diameter of the tube in the stream bed and at an angle to the flow. The spiral or vortex motion inducted throughout the length of the tube ejects the sediment intercepted by the slot-opening to an off channel reservoir where the sediment is collected. This sediment measuring device has a maximum efficiency when the Froude number of the flow is 0.7 to

0.9. There are no reports of investigations in which vortex tube ejectors have been used to measure sediment particles larger than gravel size.

## OBJECTIVE

The purpose of this study is to evaluate the performance of vortex tube ejectors and slot traps to accurately measure sediments exceeding an equivalent particle diameter of 70mm. The efficiency of these devices to intercept and accumulate sediments of relatively small sizes and in small streams is already well documented.

It is evident that slot traps, unless of monstrous dimensions, cannot contain the sediment transport of a stream except under the most moderate water and sediment discharge conditions. However, this study will determine if resorting does occur, i.e., will the turbulence of the flow over the stop trap cause the large-size sediments to be deposited and then removed in a continuous manner? What is the effective capacity of the slot trap?

The vortex tube ejector will be studied for numerous magnitudes of water and large-size sediment discharges. Emphasis will be placed on determining the magnitude of the water and sediment discharge at which the ejector becomes ineffective, i.e., to choke.

## METHOD OF INVESTIGATION

The Hydrodynamics Laboratory, Arizona State University, was used to initially study the flow phenomena and sediment interception characteristics of the slot trap and the vortex tube ejector. The study did not constitute a similitude investigation; prototype sediment similitude was completely lacking.

Models were constructed of the slot trap and allowed to accumulate sediments until resorting occurred or until the sediment, carried as bedload, bypassed the trap. Efforts were made to correlate the velocity and the Froude number of the flow to the size of the sediments deposited and then removed from the slot traps. The traps were of variable width and initially contained sediments of 50% and 75% of the total capacity of the trap.

Models were also constructed of vortex tube ejectors. All of the tubes were of the same diameter, but varied in the width of the slot opening. The flowrate in the laboratory was varied, but the tailwater level into which the vortex tubes discharged was held constant. Bedload sediments were introduced into the flow and the percentage of each sediment size intercepted by the vortex tube was recorded. The conditions were noted at which the vortex tube ejector became inoperable, i.e., choked. Observations and a qualitative analysis of the bedload sediment interception phenomena was made for the slot trap and the vortex tube ejector.

The field study was constructed to simulate a longitudinal section of a mountain stream. Methods of analysis were similar to those used in the Hydrodynamics Laboratory study.

## APPARATUS

### LABORATORY STUDY

The hydrodynamics laboratory study was conducted in a flume 6-inches wide and 20 ft. long. A false floor was constructed in the flume to permit the vortex tubes and slot traps to be installed below the channel bed. Two slot traps and three vortex tube ejectors were installed in series. The slot traps had an opening width of 5/8-inches. The vortex tubes were 1 1/2-inches in diameter and had slot openings of 1/2-, 5/8-, and 3/4-inches. The flowrates existing from the vortex tubes were controlled by a slide gate at the discharge end of the device. Point gages were used to determine water surface elevations. Flow rates were determined from calibrated orifice plates located in 4 inch and 1/2-inch header supply pipes to the flume. Sediments of approximately 1/16-, 1/8-, 1/4- and 5/16-inches in diameter were used in the study.

Figure 1. Laboratory Study Flume

Figure 2. Laboratory Vortex Tube Ejector

FIELD STUDY

A wooden rectangular channel, 4-ft. wide, 3-ft. high and 56-ft. long, was constructed in an existing stream bed. The channel had a uniform slope of 0.0189. The flow in the channel was regulated by the operation of flood gates in a dam that is located immediately upstream of the study site. The channel bed was lined with large river boulders having a maximum equivalent diameter of 9-inches. A slot trap and two vortex tubes of different diameters were installed in series. The slot trap was 2-ft. deep and the length of the opening could be varied from 2-ft. to 3-ft. One vortex tube was 1-ft. in diameter with a variable slot opening of 0 to 6-inches; the second vortex tube was 2-ft. in diameter with a slot opening of 0 to 12-inches. A rack was located at the exit of the vortex ejectors to hold the sediment intercepted by the tube in the channel. Staff gages were

located at the entrance to the flume, at the vortex tube and slot trap locations, and in the off-channel sediment reservoir located at the vortex tube's exit. The flowrates were determined from Gurley Pygmy current meter readings taken at the staff gage locations in the study channel. The revolutions of the meter were read from a revolution counter.

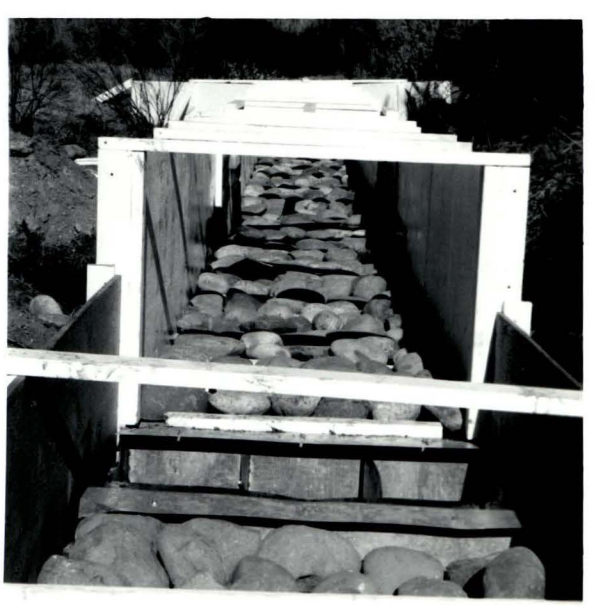


Figure 3. Upstream View of Study Channel Slot Trap is in Foreground.

Figure 4. Downstream View of the Study Site

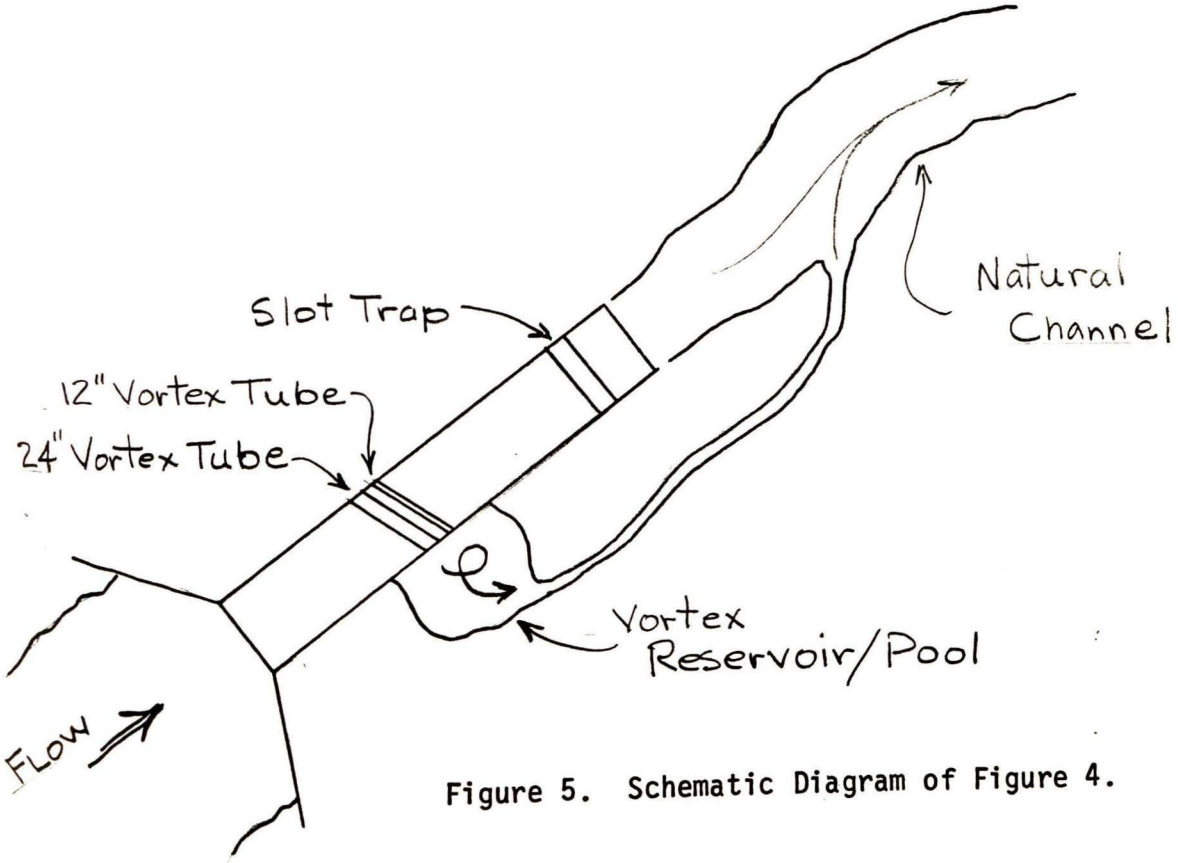



Figure 5. Schematic Diagram of Figure 4.

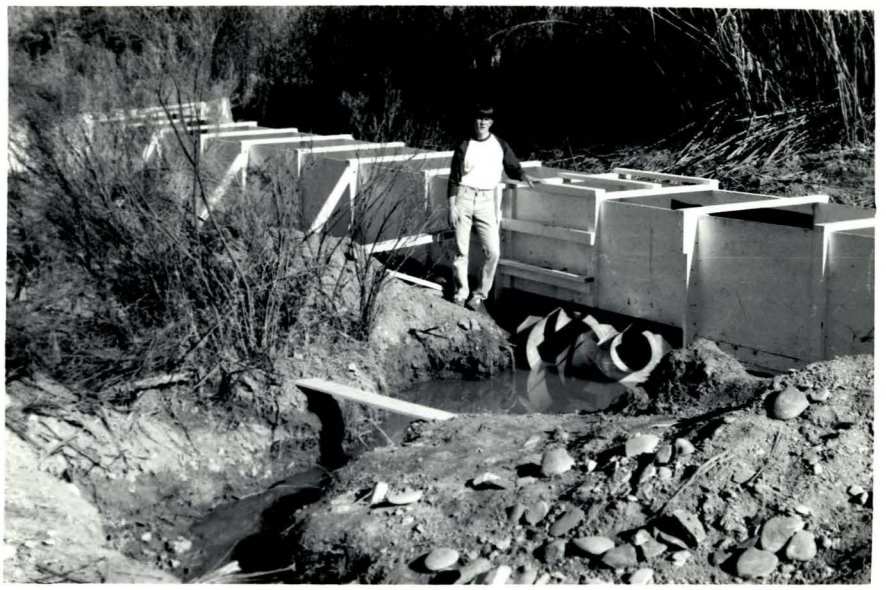


Figure 6. Vortex Tube Ejectors
and Off Channel Sediment Reservoir

# PROCEDURE

## LABORATORY STUDY

Two slot traps and three vortex tube ejectors were located in series in the laboratory channel. Observations were generally made of each device, one at a time, by closing the entrances to the remaining slot traps and vortex tubes. However, in a few instances, observations were made of two of the devices in operation. After determining the specific sediment measuring device to be studied, a flow was established and its magnitude was determined by reading a manometer connected to an orifice plate. A calibration curve was used to convert the differential manometer reading to the flowrate in cubic feet per second. The depth of water was then determined immediately upstream and downstream of the sediment measuring device being studied. For numerous test runs, because of the channel flows near a Froude number of 1.0, the water surface became wavy. A baffle was then placed at the upstream end of the flume to stablize the flow at a relatively constant depth. An equilibrium flow condition was determined when no change in water surface elevations were observed at the gaging stations. Sediments of a uniform size, and a range of sediment sizes were introduced into the flow. The percent of the total sediment load that was intercepted by the slot trap or vortex tube was observed. Photographs were taken of the sediment interception phenomena. Early in the laboratory studies, dye was injected into the channel slot trap and vortex tubes to determine the geometry of the flow. The turbulence was too great to make this

type of observation effective. The slide gates that controlled the amount of water exiting from the vortex tubes were kept at the same opening for all test runs.

FIELD STUDY

The staff gages in the flume were first calibrated by determing the flowrate and observing the staff gage readings. A flow was established by calling (radio) the operator at the dam, and informing him to increase or decrease the exsting flow. After an equilibrium flow condition had been established, i.e., constant staff gage readings, current meter measurements were made at the entrance to the channel, and at the channel exit. The flow rate at channel entrance, minus the channel exit flow rate equals the flowrate through the vortex tube. Three current meter readings were made at each staff gage location, and at equal intervals across the channel and at 0.6 times the depth of flow as noted on the staff gage. A calibration curve was then derived for staff gage reading versus flowrate so that for succeeding tests, the flowrate would be determined by reading the staff gage and obtaining the flowrate from the calibration curve. The rate of rotation of the current meter was determined from the number of revolutions read from a revolution counter for a period of 1/2- and/or 1-minute. The conversion factor to obtain the flow velocity in feet per second was one revolution per second equals a velocity of one foot per second. The revolutions per unit of time were averaged at each station to obtain an average velocity at the staff gage locations.

The water released from the dam was muddy and no observations were possible below the water surface. The flow was, therefore, stopped

after each run to observe the amount of sediment movement in the channel and into the vortex tube ejector. During one of the initial test runs, the entire sediment/boulder bed of the channel was transported downstream. The bed was replaced and then covered with a 1-inch mesh screen, and sediment/boulders were then placed on the screen-covered channel bed.

Figure 7. 2-ft. Vortex Tube Ejector Discharging Into Sediment Reservoir.

# RESULTS

## LABORATORY STUDY

The results of this study are qualitative only because of the inability to "model" the sediment transport phenomena. Nevertheless, the laboratory study for the channel flows having a Froude number of 0.6 to 0.9 indicate that slot traps may be effectively used in series, and that for approximately the same Froude number, resorting occurs at a greater rate when the trap is 1/2-full than when 3/4-full. Slot traps are not as effective as the vortex ejector for intercepting sediment, nor did the slot trap have the potential capacity for measuring large sediment discharges.

The vortex tube ejectors should not be used in series, i.e., only a single tube should be used at a specified location to measure sediment transport. The openings of the vortex tube should be designed only wide enough to intercept the relatively small sediment-sized bed material, or the largest sized material normally carried by the stream.

## FIELD STUDY

The results of the field study will be made with reference to Figure 8, "Result's Reference Graph, Field Study." The graph is presented so that the reader may become more readily familiar with the hydraulic parameters of the test runs. In this study, the 24-inch vortex tube and the slot trap were in operation; the 12-inch vortex tube was not operable.

Runs 1 through 4 were made with the channel composed primarily of uniform-sized bed material having an equivalent diameter of approximately nine inches. These runs are identified on Figure 8 as "moveable bed." No movement of the bed material was observed until a velocity of 5.78 ft. per second was reached. At this velocity a limited amount of bed material was transported downstream and entirely intercepted by the vortex tube ejector; with an increase in flow velocity to 6.67 ft. per second, Run 4A, the entire channel bed acquired motion. This bedload discharge exceeded the capacity of the vortex tube which became completely choked. The Froude number for this flow was 1.24.

Runs 5 through 7 were made with the channel bed of the same composition as for Runs 1 through 4, but a 1-inch mesh screen was placed over the bed material so that a stable bed configuration could be maintained. These runs are identified on Figure 8 as "fixed bed." Bed material, ranging in size from 3-inch to 9-inch equivalent diameter, was placed on the screen. This bed material was painted white so that the material could be easily identified in the vortex tube reservoir and in the slot trap, and downstream of the test channel if they escaped interception by the slot trap. At a velocity of 4.99 ft. per second the smaller bed material began to move downstream and was completely intercepted by the vortex tube ejector. Some bed material of all sizes remained unmoved at a velocity of 5.32 ft. per second, Fraude number = 0.90. All bed material moved downstream at a velocity of 8.36 ft. per second, Froude number = 1.33. For this flow, the vortex tube became choked at the outlet and some painted bed materials were found

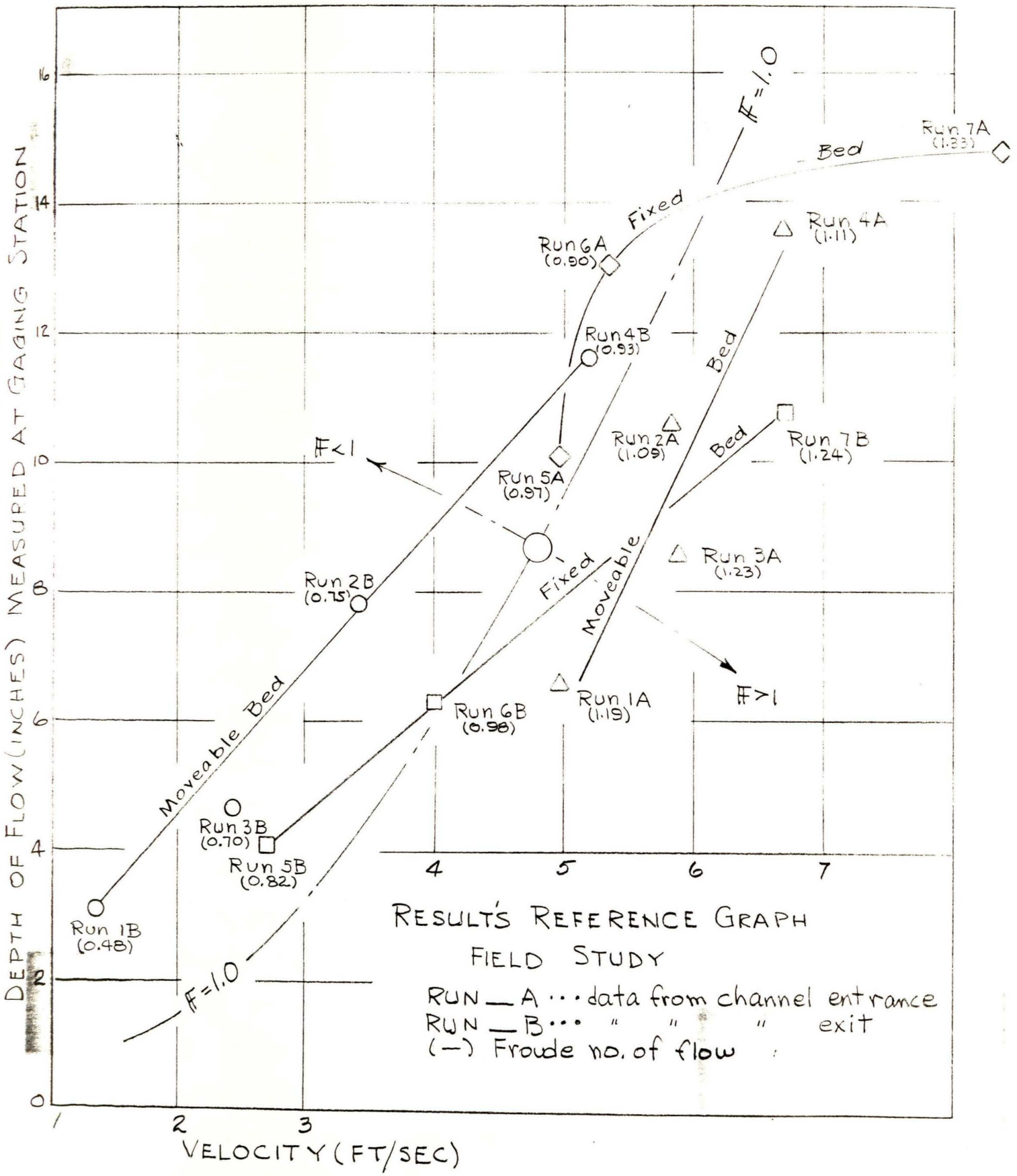
downstream of the test channel site.

Runs 5 through 7 were made with the slot trap filled with 3-inch bed material. None of the material was removed, i.e., there was no resorting.

Table 1. Water Depths in Channel and Vortex Tube Pool

| Run No. | Water Depth (ft.) | | | ΔW.S. (ft.) @ Vortex Tube |
|---|---|---|---|---|
| | Sta. 1 | Sta. 2 | Sta. 4 | |
| 1 | 0.54 | 0.29 | 0.25 | 1.06 |
| 2 | 0.88 | 0.65 | 0.65 | 0.83 |
| 3 | 0.71 | 0.40 | 0.38 | 1.03 |
| 4 | 1.13 | 0.96 | 0.96 | 0.81 |
| 5 | 0.83 | 0.58 | 0.33 | 0.94 |
| 6 | 1.08 | 0.83 | 0.52 | 0.75 |
| 7 | 1.21 | 1.13 | 0.90 | 0.60 |

Sta. 1 @ Channel entrance
Sta. 2 @ Vortex tube
Sta. 4 @ Channel exit
ΔW.S. @ Vortex tube = head on vortex tube



DEPTH OF FLOW (INCHES) MEASURED AT GAGING STATION
VELOCITY (FT/SEC)
0
2
4
6
8
10
12
14
16
1
2
3
4
5
6
7
F=1.0
F<1
F>1
Fixed Bed
Moveable Bed
Run 7A (1.33)
Run 4A (1.11)
Run 6A (0.90)
Run 4B (0.93)
Run 2A (1.09)
Run 7B (1.24)
Run 5A (0.97)
Run 3A (1.23)
Run 2B (0.75)
Run 1A (1.19)
Run 6B (0.98)
Run 3B (0.70)
Run 5B (0.82)
Run 1B (0.48)
RESULT'S REFERENCE GRAPH
FIELD STUDY
RUN __ A ··· data from channel entrance
RUN __ B ··· " " " exit
(—) Froude no. of flow


FIGURE 8

# DISCUSSION

## LABORATORY STUDY

The slot traps can be used effectively in series and their may be some merit in this arrangement. If the total bed load of a stream were to be intercepted, the most economical arrangement would be to construct several relatively shallow slot traps in series rather than one very deep trap. The accumulated sediments would also be easier to analyze. While the laboratory studies indicated a decreasing re-sorting rate with an increase in sediment accumulation in the trap, this phonemena does not appear to be intuitively correct and should be further investigated in the laboratory or field.

Vortex tube ejector installations in which the width of slot is less than the sediment size will clog at the vortex tube entrance. This action will prevent any sediment from entering the tube, and may cause a backwater effect in the channel. This action may be lessened by reducing the size of the slot opening and maintaining a relatively small velocity of flow into the vortex tube from the channel.

## FIELD STUDY

In the INTRODUCTION to this report it was noted that previous studies have determined that the vortex tube ejector has a maximum efficiency when the Froude number of the flow is in the range of 0.7 to 0.9. In this study, no large sediments were moved until the velocity exceeded 5 ft. per second and the Froude number exceeded 1.0.

It is apparent in analyzing the information presented in Figure 8, that different modes of flow existed for the "moveable bed"

and the "fixed bed." Greater velocities were obtained, for the same water depth, with the fixed bed. Apparently, only realistic flow conditions are realized when the entire bed can be put in motion by the flow. Also, apparent is the fact that the vortex tube can easily become choked at the tube entrance by a large sediment discharge, and by an accumulation of sediment in the immediate area of the tube exit. The vortex tube pool should be made relatively deep and slope away from the tube exit.

For velocities in excess of 8 ft. per second, the sediment material in the slot trap was not moved. It would appear that, for the particular slot trap design of this study, if the material in the trap became armored with sediments of 3-inch equivalent diameter or larger, that no resorting would occur of the intercepted material.

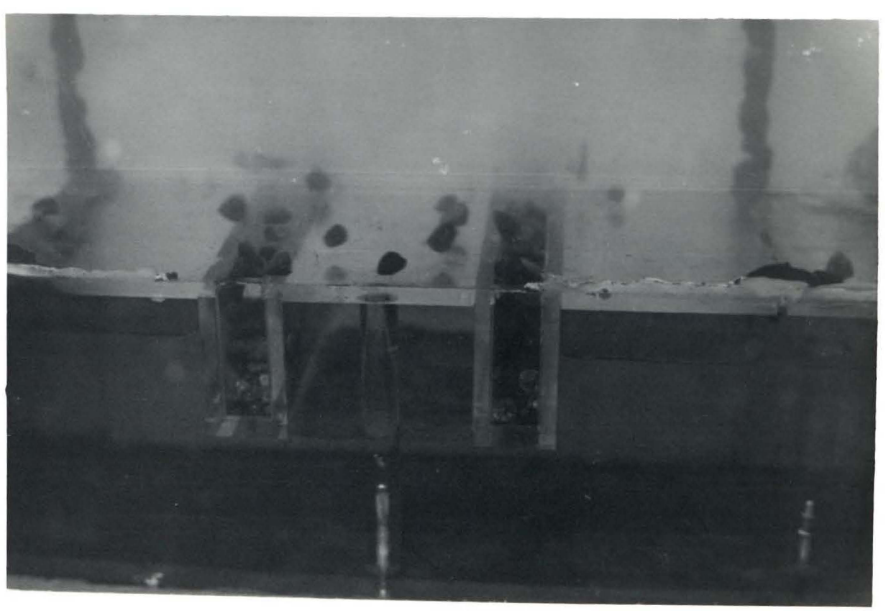


Figure 9. Two Slot Traps in Series-Laboratory Study
The flow is right to left.

Figure 10. View of Vortex Tube Choking-Laboratory Study
Slot width of tube is less than size of sediment particles.

Figure 11. Choked Exit of Vortex Tube-Field Study

## CONCLUSIONS

In a streamflow that carries any substantial amount of large-sized sediment, the slot trap is almost immediately filled with the material. A quasi armoring occurs at the surface of the sediments accumulated in a slot trap and makes resorting of these sediments minimal. Any correlation of the analysis of the accumulated sediment and the parameters of the flow cannot be determined. The slot trap is not suitable for the measurement of total bedload transport in ephemeral mountain streams.

The vortex tube ejector can be used to measure total bedload transport if the opening at the crown of the tube is made wide enough to intercept the largest sediment sizes transported by the anticipated streamflow. The reservoir or pool at the exit of the vortex ejector must be capable of accumulating the sediments intercepted by the ejector and not impede the water or the sediments being discharged into the pool.

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# APPENDIX

# LABORATORY STUDY DATA

ARIZONA STATE UNIVERSITY
College of Engineering & Applied Sciences

CIVIL ENGINEERING

HYDRODYNAMICS LABORATORY

Date 9/27/78

Experiment: HDL _____ Title: 1. VORTEX TUBE

Members of Team: CHIAN-LEE MENG (Leader) . _____ (Recorder) . _____ (Computer/Technician)

Checked by _____

Remarks _____

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ⌐ Sta "d" ¬ | | ⌐ Sta "u" ¬ | | | b = 0.464 | |
| Run no. | Manometer | $h_l$ / $h_r$ | $\Delta h$ | Q | $y_{bed}$ / $y_{w.s}$ | $y_d$ | $y_{bed}$ / $y_{w.s}$ | $y_u$ | $\frac{y_d + y_u}{2}$ | V | F |
| I | a-w | 0.56 / 0.31 | 0.25 | 0.107 | 0.970 / 1.120 | 0.150 | 1.013 / 1.150 | 0.137 | 0.144 | 1.603 | 0.744 |
| II | " | " / " | " | " | " / 1.104 | 0.134 | " / 1.129 | 0.116 | 0.125 | 1.845 | 0.920 |
| III | " | 1.04 / 0.63 | 0.41 | 0.138 | " / 1.138 | 0.168 | " / 1.157 | 0.144 | 0.156 | 1.906 | 0.851 |
| IV | " | 0.82 / 0.08 | 0.74 | 0.186 | " / 1.242 | 0.272 | " / 1.306 | 0.293 | 0.283 | 1.416 | 0.469 |
| V | " | " / " | " | " | " / 1.163 | 0.193 | " / 1.191 | 0.178 | 0.186 | 2.161 | 0.883 |
| VI | " | " / " | " | " | " / 1.176 | 0.206 | " / 1.209 | 0.196 | 0.201 | 1.994 | 0.784 |
| VII | Hg-w | -0.22 / 0.16 | 0.38 | 0.515 | " / 1.342 | 0.372 | " / 1.352 | 0.339 | 0.356 | 3.122 | 0.922 |
| VIII | " | " / " | " | " | " / 1.335 | 0.365 | " / 1.385 | 0.372 | 0.369 | 3.008 | 0.873 |
| IX | " | -0.35 / 0.30 | 0.65 | 0.650 | " / 1.441 | 0.471 | " / 1.481 | 0.468 | 0.470 | 2.981 | 0.766 |
| X | " | -0.15 / 0.08 | 0.23 | 0.415 | " / 1.245 | 0.275 | " / 1.318 | 0.305 | 0.290 | 3.084 | 1.009 |
| XI | " | " / " | " | " | " / 1.271 | 0.301 | " / 1.324 | 0.311 | 0.306 | 2.923 | 0.931 |
| XII | " | " / " | " | " | " / 1.577 | 0.607 | " / 1.625 | 0.612 | 0.610 | 1.466 | 0.331 |
| XIII | a-w | 1.51 / 0.29 | 1.22 | 0.244 | " / 1.180 | 0.210 | " / 1.233 | 0.220 | 0.215 | 2.446 | 0.930 |
| XIV | " | " / " | " | " | " / 1.263 | 0.293 | " / 1.311 | 0.298 | 0.296 | 1.777 | 0.576 |
| XV | " | 0.85 / -0.95 | 1.80 | 0.295 | " / 1.202 | 0.232 | " / 1.271 | 0.258 | 0.245 | 2.595 | 0.924 |
| XVI | " | " / " | " | " | " / 1.465 | 0.495 | " / 1.519 | 0.506 | 0.501 | 1.269 | 0.316 |
| XVII | Hg-w | -0.52 / 0.48 | 1.00 | 0.770 | " / 1.494 | 0.524 | " / 1.529 | 0.516 | 0.520 | 3.191 | 0.780 |

ARIZONA STATE UNIVERSITY
College of Engineering & Applied Sciences

CIVIL ENGINEERING

HYDRODYNAMICS LABORATORY

Date 9/27/78

Experiment: HDL _____ Title: _____

Members of Team: CHIAN-LEE MENG. _____ Leader _____ Recorder _____ Computer/Technician

Checked by _____

Remarks _____

| Sed. Size | 5/16" | 1/4" | 1/8" | 1/16" | | S.S. / R. No. | 5/16" | 1/4" | 1/8" | 1/16" | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I 1 | don't move | 100 | 100 | 100 | | II 1 | don't move | 90 | 100 | 100 | |
| 2 | OR | 100 | 100 | 100 | | 2 | OR | 80 | 90 | 90 | |
| 3 | move ↓ | 90 | 100 | 100 | | 3 | move ↓ | 90 | 90 | 100 | |
| 4 | be trapped | 100 | 100 | 100 | | 4 | be trapped | 90 | 90 | 100 | |
| 5 | | 100 | 100 | 100 | | 5 | | 80 | 100 | 100 | |
| | | | | | | | | | | | |
| VII 1 | 80 | 100 | 100 | 100 | | X 1 | 70 | 90 | 100 | 100 | |
| 2 | 90 | 90 | 90 | 100 | | 2 | 80 | 90 | 100 | 100 | |
| 3 | 100 | 100 | 100 | 100 | | 3 | 80 | 100 | 100 | 100 | |
| 4 | 70 | 100 | 90 | 100 | | 4 | 90 | 90 | 90 | 100 | |
| 5 | 90 | 90 | 100 | 100 | | 5 | 80 | 80 | 100 | 100 | |
| | | | | | | | | | | | |
| XI 1 | 90 | 100 | 100 | 100 | | XII 1 | don't move | don't move | 100 | 100 | |
| 2 | 80 | 100 | 90 | 100 | | 2 | ↓ | OR | 100 | 100 | |
| 3 | 80 | 90 | 100 | 100 | | 3 | ↓ | move ↓ | 100 | 100 | |
| 4 | 90 | 100 | 100 | 100 | | 4 | ↓ | be trapped | 100 | 100 | |
| 5 | 90 | 90 | 100 | 100 | | 5 | ↓ | | 100 | 100 | |

ARIZONA STATE UNIVERSITY
College of Engineering & Applied Sciences

CIVIL ENGINEERING

# HYDRODYNAMICS LABORATORY

Date 9/27/78

Experiment: HDL _____ Title: _____

Members of Team: CHIAN-LEE MENG (Leader), _____ (Recorder), _____ (Computer/Technician)

Checked by _____

Remarks _____

Sed. Size

| | 5/16" | 1/4" | 1/8" | 1/16" | | S.S. / R. No. | 5/16" | 1/4" | 1/8" | 1/16" | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| XIII 1 | 90 | 100 | 100 | 100 | | XIV 1 | don't move | 100 | 100 | 100 | |
| 2 | 100 | 100 | 100 | 100 | | 2 | OR | 100 | 100 | 100 | |
| 3 | 90 | 100 | 100 | 100 | | 3 | move ↓ | 100 | 100 | 100 | |
| 4 | 80 | 90 | 100 | 100 | | 4 | be trapped | 100 | 100 | 100 | |
| 5 | 90 | 100 | 100 | 100 | | 5 | | 100 | 100 | 100 | |
| | | | | | | | | | | | |
| XV 1 | 80 | 80 | 100 | 100 | | XVI 1 | Don't move | 80% Don't move | 10% Don't move | 100 | |
| 2 | 70 | 90 | 90 | 100 | | 2 | " | | | 100 | |
| 3 | 90 | 80 | 100 | 100 | | 3 | " | | | 100 | |
| 4 | 80 | 100 | 100 | 100 | | 4 | " | | | 100 | |
| 5 | 60 | 70 | 100 | 100 | | 5 | " | | | 100 | |
| | | | | | | | | | | | |
| XVII 1 | 40 | 60 | 100 | 100 | | | | | | | |
| 2 | 50 | 50 | 90 | 90 | | | | | | | |
| 3 | 40 | 70 | 80 | 100 | | | | | | | |
| 4 | 60 | 50 | 80 | 100 | | | | | | | |
| 5 | 60 | 70 | 90 | 90 | | | | | | | |

ARIZONA STATE UNIVERSITY
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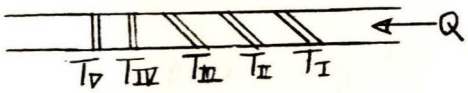
CIVIL ENGINEERING




HYDRODYNAMICS LABORATORY

Date 10/6/78

Experiment: HDL _____ Title: VORTEX TUBE

Members of Team: C.L. MENG (Leader) . _____ (Recorder) . _____ (Computer/Technician)

Checked by _____

Remarks OPEN $T_I$ and $T_{II}$
CLOSE $T_{III}$, $T_{IV}$ and $T_V$

| Run No. | Manometer | $h_l$ / $h_r$ | $\Delta h$ | Q | $y_{bed}$ / $y_{w.s}$ | $y_d$ | $y_{bed}$ / $y_{w.s}$ | $y_u$ | $\frac{y_d+y_u}{2}$ | V | F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | air-w | 0.33 / 0.14 | 0.19 | 0.093 | 1.005 / 1.382 | 0.377 | 0.962 / 1.330 | 0.368 | 0.373 | 0.537 | 0.155 |
| 2 | " | " / " | " | " | " / 1.130 | 0.125 | " / 1.074 | 0.112 | 0.119 | 1.684 | 0.860 |
| 3 | " | 0.90 / 0.64 | 0.26 | 0.109 | " / 1.150 | 0.145 | " / 1.088 | 0.126 | 0.136 | 1.727 | 0.825 |
| 4 | " | 1.20 / 0.86 | 0.34 | 0.126 | " / 1.240 | 0.205 | " / 1.185 | 0.223 | 0.229 | 1.186 | 0.437 |
| 5 | " | " / " | " | " | " / 1.158 | 0.153 | " / 1.095 | 0.133 | 0.143 | 1.899 | 0.885 |
| 6 | " | 1.35 / 0.81 | 0.54 | 0.160 | " / 1.597 | 0.592 | " / 1.549 | 0.587 | 0.590 | 0.584 | 0.134 |
| 7 | " | " / " | " | " | " / 1.200 | 0.195 | " / 1.127 | 0.165 | 0.180 | 1.916 | 0.796 |
| 8 | " | 0.30 / -0.40 | 0.70 | 0.183 | " / 1.200 | 0.195 | " / 1.143 | 0.181 | 0.188 | 2.078 | 0.853 |
| 9 | " | 0.49 / -0.37 | 0.86 | 0.210 | " / 1.228 | 0.223 | " / 1.154 | 0.192 | 0.208 | 2.176 | 0.841 |
| 10 | " | 0.91 / -0.40 | 1.31 | 0.253 | " / 1.378 | 0.373 | " / 1.326 | 0.364 | 0.369 | 1.480 | 0.429 |
| 11 | " | " / " | " | " | " / 1.261 | 0.256 | " / 1.179 | 0.217 | 0.237 | 2.306 | 0.835 |
| 12 | " | 1.60 / -0.19 | 1.79 | 0.296 | " / 1.488 | 0.483 | " / 1.432 | 0.470 | 0.477 | 1.339 | 0.342 |
| 13 | " | " / " | " | " | " / 1.291 | 0.286 | " / 1.189 | 0.227 | 0.257 | 2.487 | 0.865 |
| 14 | Hg-w | -0.21 / 0.14 | 0.35 | 0.490 | " / 1.473 | 0.468 | " / 1.416 | 0.454 | 0.461 | 2.291 | 0.595 |
| 15 | " | " / " | " | " | " / 1.412 | 0.407 | " / 1.359 | 0.397 | 0.402 | 2.627 | 0.730 |
| 16 | " | " / " | " | " | " / 1.362 | 0.357 | " / 1.294 | 0.332 | 0.345 | 3.061 | 0.918 |
| 17 | " | -0.35 / 0.30 | 0.65 | 0.650 | " / 1.480 | 0.475 | " / 1.389 | 0.427 | 0.451 | 3.106 | 0.815 |

Run No.

1 All gravel stay on flume bed

2 1/16" : 100% → Tube I

1/8" : 50% → T I
40% → T II
10% → escape

1/4" : 30% → T I
50% → T II
20% → escape

5/16" : 60% → stay on flume bed
20% → T II
20% → escape

3. 1/16" : 100% → T I

1/8" : 70% → T I
30% → T II

1/4" : 20% → T I
60% → T II
20% → escape

5/16" : 50 → stay on flume bed
20% → T II
30% → escape

4. 1/16" : 100% → T I

1/8" : stay on flume bed or → T I and stay on T I bottom

1/4" and 5/16" : stay on flume bed

5. 1/16" : 100% → T I

1/8" : 40% → T I
50% → T II
10% → escape

1/4" : 30% → T I
50% → T II
20% → escape

5/16" : 50% → stay on flume bed
20% → T II
30% → escape

Run no.

6. all gravel stay on flume bed

7. 1/16" : 100% → $T_I$

1/8" : 70% → $T_I$
30% → $T_{II}$

1/4" : 40% → $T_I$
40% → $T_{II}$
20% → escape

5/16" : 40% → stay on flume bed
40% → $T_{II}$
20% → escape

8. 1/16" : 100% → $T_I$

1/8" : 80% → $T_I$
20% → $T_{II}$

1/4" : 10% → $T_I$
60% → $T_{II}$
30% → escape

5/16" : 60% → stay on flume bed
20% → $T_{II}$
20% → escape

9 1/16" : 100% → $T_I$

1/8" : 80% → $T_I$
20% → $T_{II}$

1/4" : 20% → $T_I$
50% → $T_{II}$
30% → escape

5/16" : stay on flume bed
or → $T_I$
or → $T_{II}$
or escape
or stop at $T_I$

10. 1/16" : 100% → $T_I$

1/8" . 100% → $T_I$ and stay on $T_I$ bottom

1/4" and 5/16" → stay on flume bed

Run No.

11 1/16": 90% → $T_I$
10% → $T_{II}$

1/8": 80% → $T_I$
20% → $T_{II}$

1/4": 40% → $T_I$
40% → $T_{II}$
20% → escape

5/16": 20% → stay on flume bed
40% → $T_{II}$
40% → escape

12 1/16": 100% → $T_I$ and stay on $T_I$ bottom

1/8", 1/4" and 5/16" → stay on flume bed

13. 1/16": 100% → $T_I$

1/8": 80% → $T_I$
20% → $T_{II}$

1/4": 30% → $T_I$
40% → $T_{II}$
30% → escape

5/16": 60% → $T_{II}$
40% → escape

14 1/16": 100% → $T_I$

1/8": 90% → $T_I$
10% → $T_{II}$

1/4": 50% → $T_I$
40% → $T_{II}$
10% → escape

5/16": stay on flume bed
or → $T_I$
or → $T_{II}$
or → escape
or stop at $T_I$

Run No.

15. 1/16": 100% → $T_I$

1/8": 100% → $T_I$

1/4": 70% → $T_I$
30% → $T_{II}$

5/16": → $T_I$
02 → $T_I$
02 → escape

16. 1/16": 100% → $T_I$

1/8": 80% → $T_I$
20% → $T_{II}$

1/4": 30% → $T_I$
60% → $T_{II}$
10% → escape

5/16": 20% → $T_I$
60% → $T_{II}$
20% → escape

17. 1/16": 100% → $T_I$

1/8": 100% → $T_I$

1/4": 30% → $T_I$
50% → $T_{II}$
20% → escape

5/16": 20% → $T_I$
60% → $T_{II}$
20% → escape

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## HYDRODYNAMICS LABORATORY

Date 10/16/78

Experiment: HDL _____ Title: SLOT TRAP

Members of Team: C. L. MENET (Leader) _____ (Recorder) _____ (Computer/Technician)

Checked by _____

Remarks: OPEN $T_{IV}$ and $T_{V}$ $T_{IV}$ 3/4 full
CLOSE $T_{I}$, $T_{II}$ and $T_{III}$

| Run No. | manometer | $h_l$ / $h_r$ | $\Delta h$ | Q | $y_{bed}$ / $y_{ws}$ | $y_d$ | $y_{bed}$ / $y_{ws}$ | $y_u$ | $\frac{y_d+y_u}{2}$ | V | F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | a-w | 0.20 / -0.28 | 0.48 | 0.150 | 1.021 / 1.235 | 0.216 | 0.956 / 1.197 | 0.241 | 0.229 | 1.415 | 0.521 |
| 2 | " | 1.00 / 0.15 | 0.85 | 0.205 | " / 1.273 | 0.252 | " / 1.249 | 0.284 | 0.268 | 1.649 | 0.561 |
| 3 | " | 0.95 / -0.95 | 1.90 | 0.306 | " / 1.289 | 0.268 | " / 1.262 | 0.306 | 0.287 | 2.298 | 0.756 |
| 4 | " | 0.94 / -0.34 | 1.28 | 0.250 | " / 1.258 | 0.237 | " / 1.207 | 0.251 | 0.244 | 2.208 | 0.788 |
| 5 | " | 0.82 / -0.98 | 1.80 | 0.296 | " / 1.276 | 0.255 | " / 1.249 | 0.293 | 0.274 | 2.328 | 0.784 |
| 6 | Hg-w | -0.17 / 0.11 | 0.28 | 0.450 | " / 1.361 | 0.340 | " / 1.309 | 0.353 | 0.347 | 2.799 | 0.837 |
| 7 | " | -0.21 / 0.15 | 0.36 | 0.500 | " / 1.385 | 0.364 | " / 1.357 | 0.401 | 0.383 | 2.817 | 0.802 |
| 8 | " | -0.30 / 0.24 | 0.54 | 0.600 | " / 1.439 | 0.418 | " / 1.416 | 0.460 | 0.439 | 2.946 | 0.783 |
| 9 | " | -0.41 / 0.36 | 0.77 | 0.700 | " / 1.495 | 0.474 | " / 1.470 | 0.514 | 0.494 | 3.054 | 0.766 |
| 10 | " | -0.55 / 0.51 | 1.06 | 0.800 | " / 1.540 | 0.519 | " / 1.526 | 0.570 | 0.545 | 3.166 | 0.756 |

Run No. $T_{IV}$ 3/4



1. all gravel fall into $T_{IV}$
2. " "
3. 1/16" and 1/8": 100% → $T_{IV}$
   1/4": 80% → $T_{IV}$
   20% → $T_{V}$
   5/16": 80% → $T_{IV}$
   20% → escape
4. 1/16" and 1/8": 100% → $T_{IV}$
   1/4" and 5/16": 90% → $T_{IV}$
   10% → $T_{V}$
5. 1/16": 100% → $T_{IV}$
   1/8": 90% → $T_{IV}$
   10% → $T_{V}$
   1/4": 90% → $T_{IV}$
   10% → $T_{V}$
   5/16": 70% → $T_{IV}$
   10% → $T_{V}$
   20% → escape
6. 1/16": 90% → $T_{IV}$
   10% → $T_{V}$
   1/8": 90% → $T_{IV}$
   10% → escape
   1/4": 70% → $T_{IV}$
   10% → $T_{V}$
   20% → escape
   5/16": 70% → $T_{IV}$
   10% → $T_{V}$
   20% → escape

Run No.

7. 1/16":
90% → $T_{IV}$
10% → $T_{V}$

1/8".
80% → $T_{IV}$
20% → escape

1/4":
50% → $T_{IV}$
10% → $T_{V}$
40% → escape

5/16":
40% → $T_{IV}$
10% → $T_{V}$
50% → escape

8. 1/16":
70% → $T_{IV}$
20% → $T_{V}$
10% → escape

1/8":
60% → $T_{IV}$
20% → $T_{V}$
20% → escape

1/4":
40% → $T_{IV}$
10% → $T_{V}$
50% → escape

5/16":
20% → $T_{IV}$
10% → $T_{V}$
70% → escape

9. 1/16":
→ $T_{IV}$
or → $T_{V}$
or → escape

1/8"
40% → $T_{IV}$
20% → $T_{V}$
40% → escape

1/4":
20% → $T_{IV}$
20% → $T_{V}$
60% → escape

5/16":
10% → $T_{IV}$
90% → escape

Run
No.

10. 1/16":

→ $T_{IV}$

or → $T_V$

or → escape

1/8":

30% → $T_{IV}$

20% → $T_V$

50% → escape

1/4":

10% → $T_{IV}$

10% → $T_V$

80% → escape

5/16":

100% → escape

4/4

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CIVIL ENGINEERING

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HYDRODYNAMICS LABORATORY

Date 10/20/78

Experiment: HDL _____ Title: SLOT TRAP

Members of Team: C.L. MENG (Leader) . _____ (Recorder) . _____ (Computer/Technician)

Checked by _____

Remarks OPEN $T_{IV}$ and $T_{V}$ $T_{IV}$ 1/2 full
CLOSE $T_{I}$, $T_{II}$, and $T_{III}$

| Run No | Manometer | $h_e$ / $h_r$ | $\Delta h$ | Q | $y_{bed}$ / $y_{w.s}$ | $y_d$ | $y_{bed}$ / $y_{w.s}$ | $y_u$ | $\frac{y_d+y_u}{2}$ | V | F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | a-w | 1.37 / 0.95 | 0.42 | 0.138 | 1.020 / 1.195 | 0.175 | 0.955 / 1.155 | 0.200 | 0.188 | 1.586 | 0.645 |
| 2 | " | 1.58 / 0.72 | 0.86 | 0.204 | " / 1.240 | 0.220 | " / 1.199 | 0.244 | 0.232 | 1.895 | 0.693 |
| 3 | " | 1.05 / -0.85 | 1.90 | 0.306 | " / 1.299 | 0.279 | " / 1.264 | 0.309 | 0.294 | 2.243 | 0.729 |
| 4 | " | 0.57 / -0.10 | 1.27 | 0.250 | " / 1.268 | 0.248 | " / 1.230 | 0.275 | 0.262 | 2.060 | 0.709 |
| 5 | Hg-w | -0.17 / 0.11 | 0.28 | 0.450 | " / 1.360 | 0.340 | " / 1.327 | 0.372 | 0.356 | 2.724 | 0.805 |
| 6 | " | -0.21 / 0.15 | 0.36 | 0.500 | " / 1.390 | 0.370 | " / 1.362 | 0.407 | 0.389 | 2.774 | 0.784 |
| 7 | " | -0.30 / 0.24 | 0.54 | 0.600 | " / 1.437 | 0.417 | " / 1.415 | 0.460 | 0.439 | 2.949 | 0.784 |
| 8 | " | -0.40 / 0.37 | 0.77 | 0.700 | " / 1.470 | 0.450 | " / 1.462 | 0.507 | 0.479 | 3.153 | 0.803 |

Run No.

1. all gravel fall into $T_{IV}$

2. " " "

3. 1/16": 100% → $T_{IV}$

1/8": 90% → $T_{IV}$
10% → $T_{V}$

1/4": 60% → $T_{IV}$
20% → $T_{V}$
20% → escape

5/16": 60% → $T_{IV}$
10% → $T_{V}$
30% → escape

4. 1/16": 100% → $T_{IV}$

1/8": 100% → $T_{IV}$

1/4": 90% → $T_{IV}$
10% → escape

5/16": 90% → $T_{IV}$
10% → $T_{V}$

5. 1/16": 90% → $T_{IV}$
10% → $T_{V}$

1/8": 80% → $T_{IV}$
20% → escape

1/4": 50% → $T_{IV}$
10% → $T_{V}$
40% → escape

5/16": 30% → $T_{IV}$
10% → $T_{V}$
60% → escape

Run No.

6. 1/16":
80% → $T_{IV}$
20% → $T_{V}$

1/8":
60% → $T_{IV}$
40% → $T_{V}$

1/4":
30% → $T_{IV}$
20% → $T_{V}$
50% → escape

5/16":
20% → $T_{IV}$
20% → $T_{V}$
60% → escape

7. 1/16":
→ $T_{IV}$
OR → $T_{V}$
OR → escape

1/8":
30% → $T_{IV}$
30% → $T_{V}$
40% → escape

1/4":
20% → $T_{IV}$
20% → $T_{V}$
60% → escape

5/16":
20% → $T_{IV}$
80% → escape

8. 1/16":
→ $T_{IV}$
OR → $T_{V}$
OR → escape

1/8":
20% → $T_{IV}$
20% → $T_{V}$
60% → escape

1/4":
10% → $T_{IV}$
10% → $T_{V}$
80% → escape

5/16":
100% → escape

# FIELD STUDY DATA

Jan 12, 1979 (142)

JAN 15 — (3-4)

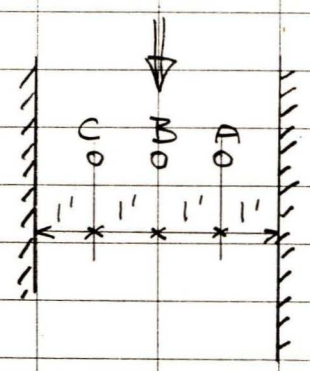
24" Vortex Tube open
12" " " closed

| Run No. | Depth of water in inches — Station 1 | 2 | 3 | 4 | 5 | 6 | Current meter Data* @ Sta 1 A | B | C | @ Sta 3 A | B | C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1A | 6 1/2 | 4 | 4 1/2 | 3 | – | 6 1/2 | 316/1' | 289/1' | 292/1' | 82/1' | 79/1' | 82/1' |
| B | 6 1/2 | 3 1/2 - 4 | 4 1/2 | 3 | – | 6 3/4 | | | | | | |
| 2A | 10 - 10 1/2 | 7 1/2 | 10 1/4 - 10 1/2 | 7 1/2 - 8 | – | 7 1/2 | 345/1' | 350/1' | 352/1' | 197/1' | 220/1' | 196/1' |
| B | 10 1/2 - 11 | 8 | 10 1/2 | 7 1/2 - 8 | – | 7 1/2 | | | | | | |
| 3A | 8 1/2 | 4 1/2 + | | 4 1/2 | – | 7 | 379/1' | 338/1' | 339/1' | 115/1' | 211/1' | 114/1' |
| B | 8 1/2 | 5 | 6 1/2 + | 4 1/2 | – | 7 | | | | | | |
| 4A | 13 1/2 - 14 | 10 | 13 1/2 | 11 1/2 | 9 1/2 | – | 417/1' | 383/1' | 400/1' | 322/1' | 320/1' | 290/1' |
| B | 13 1/2 | 13 1/2 | 13 1/2 | 11 1/2 | 9 1/2 | – | | | | | | |

Standing wave

wavy w.s.

* REV./time indicated
Vel in '/sec = 1 × rev/sec.




Current meter STA'S.

Screen over rocks composing bed of channel JAN –
24" Vortex Tube open; 12" tube Closed

| Run no. | Depth of water in inches — Station 1 | 2 | 3 | 4 | 5 | 6 | Current meter data @ Sta 1 A | B | C | @ Sta 3 A | B | C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5A | 10 | 7 | 7 | 4 | – | 8 | 268/1' | 318/1' | 312/1' | 214/1' | 157/1' | 113/1' |
| B | | | | | | | | | | | | |
| 6A | 13 | 9–10 | 10 | 6½ | – | 9 | 341/1' | 303/1' | 314/1' | 227/1' | 253/1' | 241/1' |
| B | 13 | 10 | 10 | 6 | 9 | 8½ | | | | | | |
| 7A | 14½–15 | 13–14 | 14 | 11 | 10½ | 10½ | 536/1' | 518/1' | 451/1' | 369/1' | 473/1' | 365/1' |
| B | 14½–15 | 13 | 14 | 10½ | 10 | 10 | | | | | | |